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Even the changes are changing

A new era of Cognitive Computing

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Endowed Chair of Cognitive Computing

Abstract

Watson, the computer that achieved prominence in 2011 by defeating the all time best players of the American TV quiz show, Jeopardy!, was a herald of a new age. Suddenly it was possible for machines to understand us, in our own language. In the six years since, new cognitive capabilities for machines are being announced at a dizzying pace, yet in the 60 years before Watson, computing moved comparably slowly. There are a few simple factors that have helped move us into the cognitive computing age, such as availability of data and the power of computation, but there is a deeper reason. Artificial intelligence itself has had to change, from a view of machines as perfect rational thinkers, to an understanding that cognition is intimately tied to perception, which is imperfect, and that therefore knowledge and reasoning is inherently subjective and ambiguous.

I began my research career as a graduate student at Rensselaer Polytechnic Institute in Troy, New York, in 1989. I left the field of computer networking for Artificial Intelligence, which to put things in perspective was sort of like jumping off the iceberg *onto* the Titanic. The group I had been in had just secured funding for something we called the “interNet”, and I had just finished roundly rejecting a ludicrous proposal for a “world wide web” (on the grounds that it would become dominated by porn).

Meanwhile Artificial Intelligence, the field I was joining, was passing into a period that would later be called the “AI Winter”. The first of several. But I’m not here to lament such decisions, indeed I’m quite proud of it, the way fans of certain music groups take pride in having listened to them, “before they were popular”. Although this is probably closer to “after they were no longer popular”. Still - I began research in AI when it was not popular, and I stuck WITH it through thick and thin for more than 20 years until that magic moment six years ago when we changed the world.

I won’t say that it was my team that made AI popular again, that brought us into the age where pundits shout for ethics in AI. (You know you’ve succeeded when ethicists start paying attention to you).

No, I won’t **say** that we made it popular, but you might read it somewhere.

In 2006, I was a member of the “Question Answering” team at IBM Research, and someone higher up in the company asked us whether it was possible to build a computational system that would play the American TV Quiz show, Jeopardy! Ha! Of course we said no. A year later we were asked the same question. This time we responded, “why do you want to know?” And

when we heard that answer, that IBM wanted to make it a grand challenge as they had done with chess ten years earlier, we decided to treat the question as a challenge.

5 of us did a feasibility study, and based on that we accepted the challenge. We grew the team to 12 and began. In three more years the team had grown to 35 and we were in the final stages, testing our system every week against former contestants of the show in real game settings, running thousands of experiments against a corpus of over 200,000 prior questions and answers that fans of the show kept in an on-line forum.

For a human, playing a quiz game like Jeopardy! Is hard because you have to know a lot. The breadth of knowledge touches science, history, popular culture, and a million other things. And you have to be fast. Not that I myself am particularly good at the game, but I often find myself “knowing I know” the answer to a question, yet unable to produce it in the one or two seconds the competitive environment of the game gives you to answer. For a machine, “memorizing” information is not hard. We have many ways of storing data such that we could have stored the entire contents of the web on our machines if it would have been useful. We can chain together enough machines to provide fast access to that data. But for a computational system - a machine - the hard part is *understanding the question*, and of course recognizing what among all the information it has stored is an answer. It’s one thing to memorize wikipedia, its another thing to understand it. This was our accomplishment, no system had ever exhibited this depth and breadth of language understanding before.

A few points of interest here before I continue. First, that what was trivial for the machine is what was hard for people, and vice versa. This, with just a little bit more that I will mention later, is the essential aspect of cognitive computing. Machine and human intelligence are natural allies, we complement each other well, and nothing before Watson ever effectively dispelled the more exciting science fiction meme of artificial intelligence as the ultimate enemy. Suddenly it became clear to many people that AI could make machines infinitely more useful.

Second point of interest, that we did not need to store the entire contents of the web in order to have the knowledge we needed to compete, thus finally validating the proposition that selfies and cat videos do not contribute to the sum of human knowledge. Seriously, of the hundreds of petabytes of data on the web in 2011, we only needed about a gigabyte. For the logarithmically challenged, that is less than a millionth of a percent of the web - but this does NOT say that only a millionth of a percent of the web is useful, it says a millionth of a percent is useful to play Jeopardy! As much as I love Jeopardy! (and I do), it is not and does not claim to be the ultimate arbiter of what is useful knowledge. At Google and in my research here at the VU, where I jointly find myself today, we have found the massive data on the web to be extraordinarily useful for numerous non-Jeopardy-playing tasks. I will get to that.

Third, our scientific advance was a public spectacle. It was witnessed by more than 50 million Americans, even more around the world, and received front-page news coverage everywhere. My taxi driver even recognized me the next day. In February, 2011, Watson was one of the most important and newsworthy events, becoming part of popular culture, being covered and

joked about in late-night talk shows. It made most 2011 year in review highlights. As academics, devoted to serious study, it is easy and tempting to dismiss with a desultory wave the Watson spectacle. And in 2007, when our team was sitting around a meeting room discussing the challenge before us, we felt genuine apprehension that the pop culture angle would mean that the scientific community would not take the accomplishment seriously. I am not ashamed to admit that I was one of the strongest proponents of this apprehensive view, nor am I ashamed to admit that I was wrong about it, and came to see that I was wrong about it, and that I now consider it to be of utmost importance that we, as academics devoted to serious study, do a *much better job* of communicating to the outside world what it is we do and why it is important. And if that means appearing on stage with Lady Gaga from time to time, then so be it. You can't see my poker face.

Well the good news, and part of the reason I'm here now, is that my early apprehension was overruled by clearer heads and we began our four year mission to boldly go where no one had gone before. During those years of development, we underwent several dramatic changes to our methods, challenged our tacit assumptions, and forced ourselves to define and live by metrics that we believed in. We would have only one chance on a very public stage to demonstrate a machine that could understand and answer questions at human expert quality. We couldn't deceive ourselves or adopt easy metrics in order to get a paper published or impress someone in a supervisory role. It HAD TO WORK. But the theme of my talk today is *change*. We changed our thinking dramatically in those four years, and I would like to focus on the changes that led to what we came to call Cognitive Computing, and my chair here at the VU.

As I've said, Watson was the first public demonstration of a real AI system that made the value of such systems clear. It didn't try to take over the world, it appeared smart, and most people, especially people in business, immediately recognized the value of having a machine with super-human question answering ability. I mean, how many times a day do you need to know the height of mount everest? At least 10, I would say, and that's just the tip of the iceberg. Or the glacier... Today, AI is everywhere, and we have a plethora of AI abilities that people find useful, like automatic spam detection, searching photo images, self driving cars, and on and on. It's not that Watson made these things possible, it's that Watson *changed* the public perception of Artificial Intelligence so that it was OK to say these were AI systems.

That's all fine and good, pat myself on the back - "good job chris", but the most fundamental change represented by cognitive computing is that it's OK to be wrong. We can build highly tuned machine systems that are wrong sometimes and are still seen as useful. This is a very traditional human quality - "I'm only human" we say, "bound to make some mistakes". Cognitive computing is about building systems that will make some mistakes. What did I say, mistakes? From machines? Machines don't "make mistakes", they may break from time to time, and need to be repaired, but mistakes? That's not what we've come to expect. Surely Watson couldn't have won if it made mistakes, right?

Here is a question from Jeopardy! that a very early version of Watson tried to answer, “This Frenchman is considered the father of bacteriology”. I’m sure many of you in the audience know the answer is Louis Pasteur. What did Watson think the answer was?

That’s right, “How tasty was my little frenchman”. How tasty.....what???? Is this a chilling example of what a machine was thinking, consuming little frenchmen? Well, cognitive computing systems can make mistakes, just as humans can, but they make different kinds of mistakes. Just as memorizing everything is easy for a machine, and understanding natural language is easy for a person, the mistakes we make are analogously different. A human who didn’t know the answer to the question might guess, “Napolean” or “Maurice Chevalier” - why? They are Frenchmen.

In this very early version of Watson from around 2008, we had restricted its possible answers to titles of Wikipedia articles. “How tasty is my little frenchman” is the title of a wikipedia article about a Brazilian movie based on the true story of a French ship that landed in what is now Brazil. The entire crew were eaten by cannibals. Tasty. Why did Watson think this was the answer? Well, the words in the question featured prominently in the wikipedia article, and the article was very short, which fooled one particular algorithm in our system called TF-IDF into thinking it was very important.

The final, Jeopardy! winning version of Watson would have gotten this question correct, but even this early version, with seemingly silly answers like this, performed better than average people. And there it is - machines making mistakes but still being useful, still being “better than people”. This is a big change. We had come to expect machines, and especially computers, to be unfailingly precise - that imprecision was something to be fixed. But such an expectation for most “intelligent” tasks, like answering questions, is unrealistic. To be useful, it has to be correct often enough, and when it’s incorrect it should be noticeable. Let’s look at two more examples.

“She was born Thelma Catherine Ryan on March 16, 1912 in Nevada.” I’ll wager none of you know the answer. Given a bit of time you might be able to make a good guess from the date. Watson’s answer?

Richard Nixon? Yikes.

Watson considered its two highest possibilities to be Richard Nixon and Abigail Adams, and when it answered Richard, a high-ranking IBM executive was furious. “How can it give that as an answer, Richard Nixon is obviously not a first lady, it should at least have given Abigail Adams!” (Abigail was the wife of the second U.S. president, John Adams). Don’t you agree? Richard Nixon is *obviously* not the right answer. To those of us who don’t know the answer, Abigail at least sounds plausible. She’s a woman, after all. Most Americans would even know she’s a first lady. But now which species of intelligence is showing its dark side? Who cares about gender identity? Apparently people do. I argued at the time, and I maintain today, given these incorrect choices, Richard Nixon was the best answer, because the correct answer was his wife, Pat. Abigail - frankly, that is a stupid answer. Nevada didn’t exist then, and she lived

in the early 19th century, she was dead nearly a hundred years in 1912. Richard Nixon may not be a first lady, but that's obvious, and that answer gets us something we can use. I can get from Richard to Pat. So it's not just that a machine has to be right often enough, it can be helpful even when it's wrong.

Watson's most famous "face plant" was at the end of the first of the two games it played in the televised tournament against the two greatest human players. In the category, "U.S. Cities", "Its largest airport is named after a world war II hero; its second largest after a world war II battle." If you've traveled a lot by plane in the U.S. you might know the answer here, if not, most Americans guess New York because they know JFK was a World War II hero. The answer is Chicago (the airports are O'Hare and Midway). Watson's answer?

Toronto. Toronto? Hey Watson, Toronto is not a U.S. City!

There's so much going on in this question but I want to focus on two. First, as I mentioned before, memorization is easy for a machine. Watson has perfect geographical knowledge, it knows every city, town, district, country, border, population, and so much more. It knows more than anyone here. Is there anyone here from the geography department? Watson knows more than you. And Watson knows, as most of the rest of us don't, that there are SIX U.S. cities named Toronto. So here, this exhaustive knowledge hurt Watson because when it looked for evidence that Toronto was a U.S. city, it found it.

Second, and most importantly, Watson was 90% sure that its answer was wrong. Ordinarily it would not have given an answer with this much uncertainty, but this was one of the four questions per game (four out of 61) that it had to give an answer. Unlike its human counterparts, when cognitive computing systems say they're 90% sure about something, what that means is really, "90% of the time I say I'm 90% confident I'm correct". For people, saying "I'm 90% sure" is basically meaningless. We don't think in probabilities, although there is evidence that probabilities affect us deeply, we don't retain the numbers. We don't have "provenance" for a lot of our knowledge. Cognitive computing systems are based on probabilities, they "understand" them in ways humans don't. It is essential for systems that can be wrong sometimes to be able to reflect on their own confidence - to know what they know.

Stepping back now, these changes that Watson thrust upon us were not only changes in the public perception of AI. They were the result of important changes that we, scientists who'd been working on AI for many years, underwent in our own thinking. Changes. So why do I say even the changes are changing (which is the title of this talk)? What changed that is changing? The earliest conception of artificial intelligence that goes back to the 1950s or earlier, is of computers as the perfect engines for mechanized thought. Mechanized rational thought. Free of emotion or bias, capable of "finding" the "right" answer every time. I suggest that this idea of intelligence, even of rationality, is a naive one concocted by men who idealized these characteristics of their own intelligences. These were exclusively mathematicians, the founders of AI, and so of course they believed that mathematical thinking was the most important

characteristic of intelligence. And when new people came along to study AI, we were almost always mathematicians, too, damn good ones - and this idea was carried on.

If mathematical thinking is primary, then logic, the logic invented informally by Aristotle and refined by many over the eons, including Newton, Frege, Russell, Godel, and so on, is the way in which thinking happens. Logic, then, defines the syntax and semantics of intelligence, sometimes described as the “language of thought”. Most of the people in the original Watson group, myself foremost, came from this tradition. And it made so much sense to me, it never occurred to me to question it. Human intelligence is an application of some formal logical system to data collected by each individual. Emotions are just an aberration, uncertainty an error. Obviously.

That had to change. It may be clear to some of you in the audience that this is really a shallow and limited account of intelligence, but it was a slow and painful realization for me, since it accounted for mine - and many people in AI. Some still cling to the old ways. Logic had put a stranglehold on the science of AI, stunting its growth and preventing it from solving anything but toy problems. But it was so deeply ingrained in the academic mindset of this research area and, well, you all know how that goes. Let’s face it, we are not all the free thinkers we believe we are. There was an upstart movement in AI in the 1990s that was pushing for change, and by 2007 they had reached enough legitimacy, especially in the processing of natural language, that we were using some of these inexact techniques on our team. But we all believed this was just a “hack” - a quick and dirty solution that would eventually be replaced when we had figured the logic out. But we were wrong. Watson did not use any logic, or at least, it didn’t use any form of logical reasoning, it turned out to be useless for our purposes.

I don’t really have the time, or indeed the patience anymore, to explain exactly why logical reasoning proved useless for Watson, but let’s just say that any knowledge one might represent will contain a certain error rate, and logical reasoning assumes perfect knowledge - it assumes it to the extent that in order to prove some hypothesis to be true, we negate the hypothesis and show that it adds a contradiction. If there’s already a contradiction in your knowledge, then you can prove anything to be true. This process is too brittle for understanding human language, which is full of ambiguity and rich in its variety.

Looking back, I liken the early period of AI to early mechanics. Logic is the arithmetic of intelligence, it’s the $R \times T = D$ of pre-Newtonian mechanics. The 50 years for which this was the central assumption of AI are like the 2000 years that pre-calculus sufficed for understanding how things move. Logic isn’t useless for AI, but it is overly simplistic to be its foundation, or even a significant part of it. It works only for the simplest of cases, but like $R \times T = D$, when it does work it works nicely. For better coverage of human intelligence, we needed to turn to statistical methods, primarily regression techniques. This was sort of like the discovery of calculus, or integral calculus, and for our team it was a big change. Every bit of computation that Watson did has an associated score, and these scores were combined using a logistic regression. When a computational system that *can be wrong* sometimes needs, itself, to understand that, it is necessary to have a more continuous estimate of truth.

A more continuous estimate of truth. Logic, you see, has a simple discrete notion of truth: True, and False. That's it. Since that's all there is, if something is not True, it's False. If something is not False, it's True. Ahh so simple. But insufficient, like $RxT=D$.

Why is a discrete truth value insufficient? Watson needs to evaluate and synthesize all the evidence it finds. Lets say you are trying to answer, "He was the first to summit Mt. Everest". What is the answer? Watson tried to do it by dropping the "stop words" and searching for documents that contain "first summit Mt. Everest". It all needs to be combined somehow, and Watson has learned how to do this by "training" on thousands of questions. Watson doesn't memorize the answers, which would be easy to do but wouldn't help since Jeopardy! never asks the same question twice. The training gives Watson the ability to learn how to combine its evidence scores.

Already by 2011, after our appearance on the show, new Cognitive Computing systems were appearing that did cool things. Companies like ebay, netflix, facebook, and of course google, were hesitant to add the AI label, but this changed fast in the post-Watson spectacle, and already *the changes started changing*. Just as mechanics moved from Newtonian to relativistic, the AI world evolved quickly past simple statistical models, into something called "deep learning". Deep learning bypasses a lot of the human engineering that went into Watson to solve what are for people very simple perceptual problems like speech understanding and image understanding.

Here we see Google's awesome photo search. People take so many photos these days, mostly on their phones, but they don't have time to label them. But you need to be able to search them. Photo search has learned how to recognize a few thousand fairly simple things in photos, like mountains, cities, nighttime, parties, and of course cats. Its so good at cats. Here I've searched for coastline pictures - its pretty impressive. It's cognitive computing remember - its OK to be wrong. I don't expect it to be perfect and there we can see a photo that obviously (to me) isn't a coastline. I'm sitting on a mountain like a wise guru dispensing advice. But even with that, its very useful. And I don't have to ask my grad students to label my photos anymore.

And this is what I meant all those minutes ago when most of you were still awake and I said we do have a use for so much of the data that is on the web. Photo search works because so many people put their photos on the web. Speech recognition works because so many people talked into their phones. Self driving cars work because so many people drive them. None of these are perfect, they will have to make mistakes, but the good news is: we are the baseline! We, us in this room and the further billions of our brethren out there. Cognitive computing systems will make mistakes, but fewer than any one of us does. Way fewer.

Deep learning is fully engaged and is producing new capabilities faster than anyone expected. After surmounting tasks that people do every day without really "thinking", cognitive computing is turning to tasks that require more "intelligence", like this one that I worked on at Google, in which we try to predict from a document you're writing what you might write next. Some will argue deep learning is happening because there is so much data. And that's true, we have a lot

more data than we did ten years ago. Some will argue that we have a lot more computing power. Also true. Some will argue that advances in algorithms have spurred on deep learning and its applications. Again, true. But my message is about change, the power of change; all these advances have descended like an avalanche because we finally accepted change.

But the power of change hasn't stopped. Once we accepted that things can change, we were way more open to continuing change, to questioning whether we've already gotten stuck in a rut. Just as relativistic mechanics gave way to quantum mechanics before most of the community had even accepted the former, deep learning is on the verge of giving way to something else. Let me give you a few hints about this. Throughout this talk I've said that cognitive computing systems, like Watson are better than any of you. Watson is better than anyone at playing Jeopardy! But, is it better than all of us? All of us together? Do you think that, with sufficient organization, the group of people in this room could beat Watson at Jeopardy!?

In 1906, Sir Francis Galton at a county fair in Plymouth, England, had 787 people at the fair try to guess the weight of an Ox. Not one of the participants got the right answer, or so he reports, but the average of all the participants guesses was accurate to within 1% of the Ox's true weight. This is a powerful example, and one that is often referred to as the "wisdom of crowds" or "collective intelligence". AI and cognitive computing systems need people to give them the right answers for problems that they don't know how to solve yet, so those answers have to be gathered from people.

But the first thing you encounter when you start trying to gather information from people is that they don't always agree. In Galton's case, the problem was simple: guess the ox's weight, take the average, that was "close enough" to the real answer. But what about the question we looked at before, who was the first to climb Mt. Everest. There is some controversy: Mallory vs. Hillary. But for all we know, the natives of the area climbed it all the time. So this question is really, which European? Or which white guy? And if you ask enough people the question and try to get them to answer it, you start to see disagreement, revealing the Hillary vs. Mallory controversy, the cultural centrality of the question itself. I say this to you now and you probably have no problem understanding what I'm saying.

But do you see the problem? What is the answer to the question? More importantly, how do we account for the fact that the answer varies. That, in fact, *every answer varies*, and the way the answers vary - itself varies from question to question. It may vary depending on the time, religion, culture, the region, the city, the history, the availability of some resource, the way the question was worded, and so many other things that are impossible to enumerate.

And it doesn't even stop there - there are a lot of questions that, if you ask the same person the same question at a different time, or ask the same person the same question in different ways - the answer varies. How could that be true! The problem is that questions are never as simple as they sound, there's a lot of complexity that we tend to "boil away" when answering, and if you

begin to reveal some of those dependencies, we - people - will start to account for them in our answers.

That all makes sense - or at least it should, I don't mean this to be controversial - but what does it imply for cognitive systems? Poor old Watson, a dinosaur already at six, was trained to answer questions that had one and only one answer. Jeopardy! questions were engineered to be so - the people who wrote the questions knew the answers. But in the world beyond Jeopardy!, real questions are asked by people who don't know the answer, and may not be aware of the intricate dependencies that must be specified to give even a "good enough" answer.

They may not even know the right words to ask. Look at this one, a real example from a voice query. Not sure what the right thing to do here, if this had come to me I'd probably respond in obnoxious New York fashion. But it looks like it might be an emergency, maybe something medical. When we start considering this continued broadening of the scope of something as *a-priori* simple as question answering, suddenly statistics and even deep learning appear to be trivial simplifications. In our latest work, our group is looking at a deeper mathematical treatment in which we change something even more fundamental than logic was to AI.

I'm talking about truth. Even when statistics came along and disrupted the world of logic in AI, even when deep learning came along and disrupted that, we still had under it all this innocuous and fundamental assumption: every problem has a true solution, every question has a true, or several true, answers. In our experiments gathering information from lots of people, it has become clear that this is an over-simplification. Truth is as rich, subtle, nuanced as anything else we've ever encountered. You may think I'm talking about fake news or something like that, but no - I'm talking about all the cases I've talked about today. From Edmund Hillary to treating typhus: evidence, context, time, history, gender, race, religion, economics, geography, weather and on and on and on, all these things impact what we think of as truth. We think this will be a big change. Can you handle it?

To the students in the audience, I suggest this. Don't be afraid to change, to question your assumptions and find your own hidden bias. Question your elders, and especially your heroes. Unless of course they are me.

Thank you for listening, and Thanks firstly to the board of directors of the university for their faith in me, and to Google as well who approved the appointment. I should also thank IBM for the Watson project and what was the highest point in my professional career. I especially want to thank his majesty, sorry reverence, sorry honor? Professor Schreiber, who deserves the most credit for my appearing here today, thanks for all your work when you led the Web & Media group, became head of department and now as dean - you made this an institution I wanted to be part of. Of course the rest of the faculty and staff of the VU and of UVA who were also responsible for this appointment and went to great lengths to make it so. I have to acknowledge my family, who came all the way from New York, my father and mother who did all those annoying parental things during my youth to be sure I continued my studies and made it up here

- top 'o the world, ma! - my children who gave me the opportunity to appreciate how hard it was for my parents to have done all that. I love you and I'm so glad you're here. Finally to my wife who is my closest friend and colleague, my inspiration, my compass, who made many of my slides so beautiful and shared the creation of many of these ideas - thank you, I don't know how I ever lived without you.

Ik heb gezegd.